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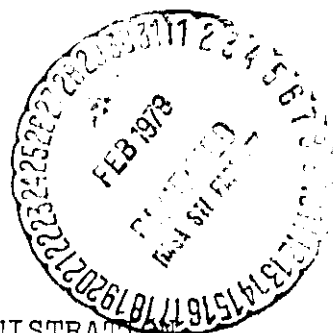
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CERTAIN PECULIARITIES OF THE FUNCTIONING OF THE CARDIOVASCULAR
SYSTEM IN BEDREST CONDITIONS DURING HORIZONTAL AND ANTIORTHOSTATIC BODY
POSITIONS

Anonymous

(NASA-TM-75075) CERTAIN PECULIARITIES OF THE FUNCTIONING OF THE CARDIOVASCULAR SYSTEM IN BEDREST CONDITIONS DURING HORIZONTAL AND ANTIORTHOSTATIC BODY POSITIONS (National Aeronautics and Space Administration) 27 p G3/52 05475 N78-18699 Unclass

Translation of "Nekotoryye Osobennosti Funktsionirovaniya serdechno-sosydistoy sistemy v usloviyakh postel'nogo rezhima pri gorizontally i antiortostaticheskom polozenii yakh tela", "Interkosmos" Council, Academy of Sciences, U.S.S.R., and Directorate of Space Biology and Medicine, Ministry of Health, U.S.S.R., Moscow, Report, 1977, pages 1-33.



NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D. C., 20546 JANUARY, 1978

1. Report No. NASA TM 75075	2. Government Accession No.	3. Recipient's Catalog No.	
4. Title and Subtitle CERTAIN PECULIARITIES OF THE FUNCTIONING OF THE CARDIOVASCULAR SYSTEM IN BEDREST CONDITIONS DURING HORIZONTAL AND ANTI- ORTHOSTATIC BODY POSITIONS		5. Report Date January, 1978	6. Performing Organization Code
7. Author(s) Anonymous		8. Performing Organization Report No.	10. Work Unit No.
9. Performing Organization Name and Address SCITRAN Box 5456 Santa Barbara, CA 93108		11. Contract or Grant No. NASw-2791	13. Type of Report and Period Covered Translation
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D.C. 20546		14. Sponsoring Agency Code	
15. Supplementary Notes Translation of "Nekotoryye Osobesnnosti Funktsionirovaniya serdechno-sosydistoy sistemy v usloviyak postel'nogo rezhima pri gorizontāl nom i antiortostaticheskom polozeniyakh tela", "Interkosmos" Council, Academy of Sciences, U.S.S.R., and the Directorate of Space Biology and Medicine, Ministry of Health, U.S.S.R, Moscow, Report, 1977, pp. 1-33.			
16. Abstract The large amount of factual and experimental material accumulated up to the present time, obtained during the preparation and execution of manned space flights by the U.S.S.R. and the U.S., permits us to consider the state of weightlessness as one of the chief factors limiting man's extended stay in space. In this connection, the adequate modeling of physiological reactions inherent to the state of weightlessness has become a matter of particular urgency in space medicine. This modeling is necessary for studying the phenomenology and degree of disorders, prognostication of the crew's health, and developing the various preventive measures employed in space flights.			
17. Key Words (Selected by Author(s))		18. Distribution Statement Unclassified - Unlimited	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 26	22. Price

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The large amount of factual and experimental material accumulated /1*
up to the present time, obtained during the preparation and execution
of manned space flights by the U.S.S.R. and the U.S., permits us to con-
sider the state of weightlessness as one of the chief factors limiting
man's extended stay in space. In this connection, the adequate mode-
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has become a matter of particular urgency in space medicine. This
modeling is necessary for studying the phenomenology and degree of
disorders, prognostication of the crew's health, and developing the
various preventive measures employed in space flights.

Despite occasional critical remarks associated with the imperfec-
tion of currently-employed models (immersion, bedrest), the results of
medical examinations of Soviet cosmonauts and American astronauts have
convincingly shown that prognoses based on these examinations have pro-
ven to be correct. This is primarily applicable to such disorders as
lowering of orthostatic stability and physical working capacity, im-
pairment of vertical stance regulation and coordination of movements
when walking, reduction in the strength of anti-gravitational tonus,
impairment of a number of metabolic processes in the organism, and so
forth.

The unilateral changes noted after space flights and after model /2
experiments lead to the assumption that it is possible not only to

*Numbers in margin indicate pagination in foreign text.

reproduce some effects of weightlessness under Earth's gravitational conditions, but also to evaluate various means of preventing and treating known disorders, the range of which has been rather accurately determined. Some of them approach the upper limit of the physiological norm while others, predominantly those of the circulatory system, may be qualified as subpathological changes that limit man's extended stay in space.

Medical and biological research conducted as part of the flight programs of the "Soyuz" and "Apollo" spacecraft, as well as the Salyut and Skylab orbital stations, has shown that one of the basic developments of space medicine in the coming years will be the further study of the subtle adaptive mechanisms of man's circulatory systems while in a weightless state. A purely physical phenomenon - the absence or sharp reduction of fluctuations in the hydrostatic component of blood pressure - plays a very important role in the etiology of the restructuring of the functioning of many systems under these conditions. The natural response to this phenomenon is commonly thought to be an unusual (for Earth conditions) redistribution of blood, with increased flow to the organs and parts of the body lying above the level of the heart. This is followed by the development of compensation processes with the participation of neuroflexor, metabolic, and myogenic mechanisms. The problem of gravitational redistribution of blood, under particularly intense study in recent years, is in many ways obscure, but its role in the development of cardiovascular system disorders is fully /3 evident. A stereotype of muscular functioning in weightlessness with hypokinesia and hypodynamics, uncommon for conditions on Earth, is another very important pathological factor.

Both of the above mentioned factors can be simulated in experiments on the earth and serve as the basis for modeling the physiological effects of weightlessness. The correctness of this model is presently being reinforced in science as the result of a wide range of research efforts conducted chiefly in the U.S.S.R. and the U.S., and special discussions of this problem in international conferences, as well as at the 4th and 7th meetings of the joint Soviet-American work group in space biology and medicine. A basic model accepted in our country in recent years is antiorthostatic hypokinesia with a body

position declination angle of -4° (head lower than feet). The experiment's duration is dictated by the objectives of the research.

The use of a hypodynamic model with the subjects in an antiorthostatic position has brought some additional developments in simulating the effects of weightlessness that are reproduced less accurately or not at all when the body is in a horizontal position. This was expressed in the appearance of the sensation of blood rushing to the head (which gradually smoothed out), hyperemia and pastiness in the face, the appearance in some instances of the illusion of an overturned body position, and so forth. These phenomena are accompanied by substantial changes in blood redistribution, these being directly indicated by the results of radioisotope investigations (Table 1). Gravitational redistribution of blood is confirmed by rheographic data [1] and materials obtained during a study of the veins of the ocular fundus [2]. /4

Table 1: Distribution of blood (ml) in various parts of the human body.

	in a horizontal position	at -4° (head lower than feet)	at -4° for 45 days
Head	666	735	728
Chest	1263	1407	1575
Abdomen	819	925	835
Pelvis	624	678	714
Legs	1099	799	626

BRIEF EXPERIMENTS WITH VARYING BODY POSITION UNDER BED REST CONDITIONS

It is most advisable to begin a comparison of the physiological effects brought about by bed rest in a horizontal and antiorthostatic body position with the study of the influence of brief antiorthostatic hypokinesia, simulating the "acute" period of adaptation to weightlessness, on circulation and on a number of involved analytical systems.

The impact of this period is known to be particularly great during short space flights or flights in orbital stations, since it is at this time that docking of the craft with the orbital station occurs, along with the transfer of the crew into the station, preparation of equipment, and a number of dynamic operations dealing with the running of the orbital complex. Moreover, it is during this period that the process of gravitational redistribution of blood is most expressed and the symptoms of motion sickness most clear.

A strict 5-day bed rest with horizontal (0°) and antiorthostatic body position at angles of -4° , -8° , and -12° was used for simulating the "acute" period of adaptation to the weightless state. These data were presented by us in detail in 1976 at the seventh meeting of the joint Soviet-American group in the city of Yerevan [4] and published [5, 6]. The chief observations from the experiments with antiorthostasis are shown in Table 2.

Table 2: Basic Symptoms in 5-Day Antiorthostasis Hypokinesia

Symptoms	0°	-4°	-8°	-12°
Reduction of taste and smell sensitivity threshold	-	+	+	++
Sensation of rushing blood and heaviness in the head	-	+	+	++
Nasal Congestion and impeded breathing through the nose	-	+	++	+++
Oedematosis and enlargement of the nostrils	+	++	++	+++
Increase of intranasal resistance	+	+	++	+++
Discomfort of the nasopharynx, hoarseness, congestion of the pharynx	-	+	+	++
Hyperemia of the external auditory canals, of the veins of the eardrum	-	+	+	++
Dizziness and nausea	-	-	+	+

Symptoms	0°	-4°	-8°	-12°
Illusion of "rocking", head-down body position, falling sensation	-	+	+	++
Nistagmoid movements of the eyeball	-	+	+	++
Stiffness of the face and congestion of the vessels of the sclera and conjunctiva	-	+	++	++
Sensation of fullness in the eyes, eye fatigue when reading reduction in acuity of central vision	-	+	++	++
Increase in diastolic pressure in the central retinal artery.	+	++	+++	+++
Increase of the retinal-brachial index	+	+	++	++
Increase in intra-ocular pressure	+	+	++	++
Edema of the retina	-	-	+	++
Impairment of postural balance when walking	+	+	++	+++
Impairment of vertical pose regulation	+	++	++	+++
Reduction of orthostatic stability	+	++	++	+++
Reduction of physical work capacity	-	+	+	+

Note: The symbol (+) indicates presence of symptom
The symbol (-) indicates absence of symptom

It should be again emphasized that research data have permitted us to model the initial period of man's adaptation to the weightless /7 state and, in particular, to evaluate the significance of blood redistribution during the above noted physiological reactions. It has been shown that antiorthostatic hypokinesia with tilt angles from -4° to -12° more accurately reproduce those reactions noted in cosmonauts as

a result of orbital flight than bed rest in a horizontal body position. Very similar data were obtained by our American colleagues [7] in experiments with brief antiorthostatic hypokinesia at an angle of -5° .

PROLONGED EXPERIMENTS WITH VARYING BODY POSITIONS UNDER BED REST CONDITIONS.

Series 1. The subjects of this series of tests underwent a strict 30-day bed rest in horizontal (0°) and antiorthostatic (-4°) body positions. On the whole, the general symptoms of disorders corresponded with those noted in the short-term experiments [8, 9, 10]. During the first hours in an antiorthostatic position, all subjects sensed a rushing of blood to the head and a feeling of heaviness in it, as well as pulsation in the temple area. These sensations reached maximum intensity within approximately three hours after the beginning of the experiment. Some subjects reported a feeling of pressure, swelling of the skin of the face, especially under the eyes and in the area of the ears. A sensation of raised temperature of the facial skin also appeared. Individual subjects complained of the sensation of blood rushing to the nasopharynx, through the nose, and lowering of the timbre of the voice. Blood rushing to the head was accompanied by a pulsating headache. When the eyes were closed, during the first hours of the experiment, there appeared distinct illusions of "falling" and "toppling" of the body.

Objectively, hyperemia of the facial skin was detected in all subjects, especially intense in the area of the ears. The skin on the upper chest area was of a rosy hue. The illusion of body position generally disappeared during the first day of bed rest; the rushing of blood to the head and the sensation of bed tilting ended toward the close of the second day. However, the process of adapting to the unaccustomed state continued with individual variations and on the whole was completed in the first half of the experiment. The subjects characterized the second half of the experiment as a period of essentially complete adaptation to the antiorthostatic body position.

No illnesses of any kind stimulated by the redistribution of

blood were detected in the course of the experiment. General clinical urine and blood tests did not reveal any significant changes. Pulse frequency and arterial pressure were within normal limits. Table 3 shows changes in some indicators of hemodynamics and gaseous interchange occurring in model experiments without the use of preventive measures [11].

As seen from the data, during bed rest in a horizontal position beginning from the fifth through the 20th day an increase of cardiac output is observed due to the heart's pumping volume, then as the pulse rate was practically unchanged, oxygen consumption had a tendency to decrease.

In the antiorthostatic position, the increase of cardiac output and gaseous interchange is noted even from the first days of bed rest. /9 Beginning with the fifth day a reduction of oxygen consumption and discharge of carbon dioxide is observed in the subjects, while cardiac output remains elevated due to the heart's pumping volume.

During our study of hemodynamics under conditions of strict bed /11 rest we repeatedly noted an increase of cardiac output. In an earlier conducted 15-day experiment [12] it was also noted that cardiac output grows from the sixth through the ninth day of bed rest (0°), which closely corresponds to the above-described changes during 30-day bed rest in a horizontal body position (0°). In contrast to this, an increase in cardiac output is observed from the very beginning of bed rest in an antiorthostatic body position (-4°), which in all probability is brought about by the considerably great flow of blood into the upper chest and heart region.

Series 2. Participating in the experiments were essentially healthy subjects aging from 19-35 years (24 people), who were divided into four groups of six in each group. Those observed in the first, second, and third experimental groups observed a strict 30-day bed rest in an orthostatic ($+6^\circ$) and antiorthostatic (-2° and -6°) body position, respectively. The members of the fourth group (control) were not subjected to bed rest. During the course of the entire experimental period they were under identical conditions of housing, daily activities, diet

Table 3: Change in some indicators of Hemodynamics and Gaseous Interchange in Subjects During 30-Day Bed Rest in a Horizontal (0°) and Antiorthostatic (-4°) Body Position.

Body Position	Index	Background	Bed Rest (days)						
			1	2	3	5	10	15	20 25-26
0°	Cardiac Output	5.32	5.09	-	-	5.70	7.30	5.89	6.65 5.12
	Beat Output	85	84	-	-	92	110	94	106 81
	Pulse Rate (beats/min)	60	60	-	-	60	61	62	61 64
	Oxygen Consumption (ml/min)	298	281	-	-	287	283	253	270 271
	Carbon Dioxide Discharge	234	238	-	-	229	239	235	221 208
-4°	Cardiac Output	5.30	6.87	5.72	7.48	4.31	6.03	6.83	5.80 6.02
	Beat Output	80	119	90	123	68	104	108	91 85
	Pulse Rate (beats/min)	69	57	64	61	63	58	64	64 70
	Oxygen Consumption (ml/min)	229	273	288	246	201	212	210	192 181
	Carbon Dioxide Discharge	223	232	261	213	169	178	168	164 161

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and water consumption as the subjects of the experimental groups. The reduced moving activity, unavoidable under stationary conditions, was supplemented with a special complex of physical exercises. Analysis of the resulting data showed that the clinical condition of the subjects and their ability to undergo various functional tests (orthostatic, work on a veloergometer, ODNT and so forth) after the completion of the experimental period was practically unchanged. In the subjects of the experimental groups (1, 2, 3), varying changes in the functioning of individual physiological systems were detected under the influence /12 of 30-day bed rest.

The symptomatic complex of disorders characteristic of the "acute" period of adaptation to bed rest conditions prevailed during the first days of the experiment; however, the expression of individual impairments was found to depend closely on the body position in the bed: in an orthostatic position ($+6^\circ$) the subjective and objective signs of blood redistribution were insignificant, but in the antiorthostatic positions (-2° and -6°), they were clearly expressed. Beginning with the second half of the experiment, the differences in the clinical status of the subjects of the three groups leveled out to a significant degree.

In the subjects who were in an antiorthostatic position, a feeling of blood rushing to the head appeared during the first two days of the experiment, and when the eyes were closed an illusion of the body being tilted from 110 to 140° to the vertical appeared. There was a sharp increase in the error of perception of visual coordinates (almost doubled in the -6° group), determined using a "vertical" instrument. Toward the middle of the experiment, the error in perception of the subjective visual vertical was somewhat decreased in comparison with that registered during the first days, but it still substantially exceeded the initial value. Testing during the final days of bed rest again revealed a tendency toward increase of the error. During ten days of the rehabilitation period, a stable (-6° group) or singular increase of perception error was observed to be at the same level as during the first days of hypokinesis (-2° group).

In subjects remaining in an orthostatic position ($+6^\circ$), the change

in perception of the subjective visual vertical was more pronounced. /13
During the first hours of hypokinesia, these subjects, in contrast to subjects of other groups, experienced an illusion of the head and body being tilted at an angle of 40-60° to the vertical when the eyes were closed. A single increase in perception error was noted in these subjects in the middle of the experiment, in addition to pronounced persistent asymmetry at its end [13].

The impairments of perception of the visual vertical, revealed during the initial periods of antiorthostatic hypokinesia and rehabilitation, are rather characteristic of the initial period of space flight and the first days of re-adaptation to Earth's gravity, since during these periods cosmonauts and astronauts most often note the development of various disorders [14 - 21].

After completion of the 30-day bed rest, the ability to withstand the functional tests was substantially reduced in subjects of all three groups. In those cases where the function under study depended on the reduction of hydrostatic blood pressure, the reduction of the ability to undergo functional tests depended on the position of the body in the bed; the most pronounced changes were noted in subjects who remained in an antiorthostatic body position at an angle of -6°; in other cases, where the parameter under study was seldom subject to the effects of gravitational redistribution of blood, the changes after completing bed rest remained practically identical to that of subjects in an orthostatic, as well as antiorthostatic, position in the bed. We shall present the results of individual functional tests as examples.

Active Orthostatic Test. The test consisted of the subject being initially in a horizontal (5 min) position and an active standing /14 position (10 min). The frequency of heart contractions was continually registered on an EKG and the discrete-arterial pressure by the tachoscillograph method. The results of the completed research are shown in Table 4.

From the table, it can be seen that the ability to undergo active orthostatic tests after completing bed rest was substantially reduced

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in all subjects; the most pronounced deterioration of postural regulation of the circulatory system was observed in persons who were in an antiorthostatic position at an angle of -6° . Thus, the difference in frequency of heart contractions registered in the vertical position before, and 24 hours after completing bed rest, totalled on the average +16, +26, and +32 beats/min for subjects kept at angles of $+6^{\circ}$, -2° , and -6° respectively. The difference in increase of the pulse rate when switching from a horizontal to a vertical position before and after completing the experiment also was equal to +12, +16, and +20 beats/min respectively, i.e., the quickening of the rhythm of heart contractions upon assuming a vertical position was most pronounced in subjects of three groups (-6°) as compared with background data.

Passive orthostatic test ($+85^{\circ}$ - 20 minutes). During the conducting of the test, the frequency of heart contractions was continuously registered by EKG and the discrete-arterial pressure by auscultation. Table 5 gives the average values of indicates over a ten-minute period of horizontal position and the maximum values of frequency of heart contractions, as well as the minimum values of arterial pulse pressure, registered in a vertical body position. /16

The results of research have shown that, under the influence of a 30-day bed rest, there is an increase of the frequency of heart contractions and an increase of arterial pulse pressure in a horizontal position. There is also a pronounced quickening of the rhythm of heart contractions and a reduction of arterial pulse pressure in a vertical body position, somewhat more pronounced in subjects who were in an antiorthostatic position in bed. Thus, the difference in maximal pulse frequency registered in the vertical position before and after completion of bed rest totalled +26, +39 and +48 beats/min for subjects who were in an orthostatic ($+6^{\circ}$) and antiorthostatic (-2° and -6°) body positions, respectively. At the same time, after completing bed rest, three cases of faintness were observed in the first group ($+6^{\circ}$), four cases in the second group (-2°), and two cases in the third group (-6°). To a certain extent, this reduces the strict dependence of the lowering of orthostatic stability on the negative tilt angle during bed rest.

It should be noted that subjects of two experimental groups ($+6^{\circ}$

and -2°) where the greatest amount of faintness was observed after completion of bed rest, were, to a certain degree, orthostatically less stable than subjects of the third group (-6°), which is evidenced by the considerably better reaction of the latter in background investigation. One can thus make the preliminary conclusion that within the limits of the 30-day experiment, the change of orthostatic ability is a function of body position in the bed.

Test with Maximal Physical Load on a Veloergometer. The funda- /18
mental goal of the test is an investigation of the physical work capacity and condition of the cardio-respiratory system of man. Man's physical work capacity, i.e., his ability to perform intensive muscular work, in a certain time period, is closely linked with the reserve capabilities of the oxygen transport and utilization system. Since during the process of supplying oxygen to the working tissues, the primary role is played by the cardio-respiratory branch of this system, when its functional capabilities are increased, the work capacity of the organism increases; when this functional capability is decreased, the work capacity is reduced. It follows that information on the condition of this system provides a well-founded physiological explanation of the change in the level of man's physical work capacity. It is presently recognized that in investigating man's work capacity, the most valuable tests are those that permit us to determine maximum oxygen consumption ($\max \text{VO}_2$) - the international standard for an organism's cardio-respiratory potential - by a direct method. Research of the cardiovascular and respiratory systems under conditions in which a subject performs maximum dynamic muscular work is of important practical significance, not only for specialists of various fields of applied physiology, but also for clinicists, since it permits them to uncover concealed pathology.

The test offered can be used in solving a number of problems of space medicine of a general, as well as a particular, nature. The following can be included: clarification of mechanisms of the organisms' adaptation to stress effect during limited muscular load; an investigation of the possibility of predicting the development of physical de-training in model experiments using various preventive measures and an evaluation of their effectiveness; a comparison of data obtained from

Table 4: Frequency of Heart Contractions (beats/min) in subjects During an Active Orthostatic Test Before and After completion of a 30-Day Bed Rest in an Orthostatic (+6°) and Antiorthostatic (-2° and -6°) Body Position.

Bed Rest	Observation Period	Horizontal Position	1	2	3	5	6	8	10	M
+6°	Before	65.8 ± 1.76	88	86	89	91	90	90	95	90.2 ± 2.45
	After	71.3 ± 2.45	94	100	108	107	107	110	118	106.6 ± 2.79
	Difference	< 0.1	> 0.1	> 0.1	> 0.1	> 0.1	> 0.1	< 0.1	< 0.05	± 6.4 ± 0.6
-2°	Before	59.2 ± 1.25	76	77	78	80	80	82	87	80.1 ± 1.88
	After	68.8 ± 0.74	99	98	103	105	102	108	123	105.7 ± 2.06
	Difference	< 0.001	< 0.01	< 0.01	< 0.01	< 0.001	< 0.01	< 0.01	< 0.001	± 5.6 ± 0.001
-6°	Before	63.2 ± 1.30	75	73	74	76	73	74	79	75.0 ± 1.02
	After	69.3 ± 1.97	94	100	102	110	110	111	122	107.1 ± 2.13
	Difference	< 0.02	< 0.01	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	± 2.1 ± 0.001

Earth experiments with the results of examinations of crew members during actual space flights in order to establish a correlation between them. /19

Test Procedures and Registered Indicators. The test is performed on a veloergometer in the sitting position with the legs turning the pedals at a constant speed (65 ± 5 rev/min). A load equal to 600 kgm/min during the first minute of the test is increased in steps of 200 kgm beginning with the second minute and each succeeding minute until the subject reaches total fatigue, and is no longer able to perform the work at the assigned rate (when circumstances indicate, the test can be stopped at any point).

The following parameters are registered at a state of rest, while performing the work and during the recovery period:

- frequency of heart contractions and EKG;
- gaseous interchange (consumption of oxygen and carbon dioxide discharge);
- minute ventilation of the lungs.

The registered and rated indicators provide the possibility of completely evaluating the functional potentials of the cardiovascular and respiratory system of the subject, and to reach a concrete conclusion about his physical work capacity.

Since the load begins at a level of 600 kgm/min and is increased in steps, a measured physical load of smaller intensity is generally conducted before the test. This prepares the organism for performing the heavy physical work. /20

In the opinion of the majority of researchers, the change of hydrostatic pressure of organic fluids (particularly blood) and limited muscular activity serve as the chief factors contributing to the deterioration of the functional condition of the human organism after extended stays in a weightless state or under conditions of simulating a weightless state (bed rest and water immersion). Along with this, the significance of each of these factors in reducing the functional capacities of the organism, and particularly the cardiovascular system, has still

Table 5: Frequency of Heart Contractions (beats/min) and Arterial Pulse Pressure (mm mercury column) in Subjects During a Passive Orthostatic Test Before and After Completion of a 30-Day Bed Rest with Orthostatic (+6°) and Antiorthostatic (-2° and -6°) Body Positions.

Bed Rest	Observation Period	Frequency of Heart Contractions		Arterial Pulse Pressure (mm mercury)	
		Horizontal Position	Vertical Position	Horizontal Position	Vertical Position
+6°	Before	62	95	52	35
	After	72	121	57	21
	Difference	+10	+26	+5	-14
-2°	Before	55	87	43	28
	After	68	126	53	15
	Difference	+13	+39	+10	-13
-6°	Before	59	84	52	45
	After	77	132	60	23
	Difference	+18	+48	+10	-22

not been sufficiently studied. Therefore, a comparison of data obtained in a homogeneous group of subjects before and after an extended stay under conditions of ortho- and antiorthostatic hypokinesis is of very pressing importance in clarifying this problem. The absence of a statistically meaningful intergroup difference in change of maximal oxygen consumption and overall volume of work performed points to the conclusion that the fundamental cause of deterioration of the organism's functional condition is not the difference in change of hydrostatic pressure of organic fluids, but rather hypokinesis, inasmuch as the limitation of muscular activity was identical in all groups (Table 6).

Table 6: Change in Values of Maximal Oxygen Consumption and Volume of Work Performed After 30-Day Hypokinesis Under Conditions of Orthostatic (+6°), Essentially Horizontal (-2°), and Anti-Orthostatic (-6°) Body Positions

Group	Max VO ₂ , l/min			Overall Volume of Work Performed		
	Before	After	%	Before	After	%
+6°	3.38	2.75	-18.6	9596	7993	-16.7
-2°	3.30	2.59	-21.5	9134	6864	-24.8
-6°	3.39	2.76	-18.6	9244	7736	-16.3

Thus, despite certain differences in the course of a number of processes in Earth experiments, for weightlessness, it should be acknowledged that bed rest serves as an adequate model of weightlessness, permitting us not only to understand more deeply the essence of physiological restructuring that appears in the organism in the absence of gravity, but also to develop effective means of prevention and rehabilitation. Primary importance in the change of physical work capacity functional condition of the cardio-respiratory system in model experiments should evidently be given to the degree and duration of the limitation of moving activity, and not to change the body position (in any case, from +6° to -6°), with respect to the gravitation vector.

It is interesting to note the fact that in those experiments where physical training was used as a preventive measure (regardless of the presence or absence of other preventive measures), the subjects

did not complain of shortness of breath during the veloergometric tests conducted after bed rest. In the control experiments, however (duration from 14 days and more), the main complaint after completing hypokinesia during the veloergometric tests was acute shortness of breath. In the background investigations, those administering the test to all groups as a rule stopped work on the veloergometer due to fatigue of the thigh extensors. Shortness of breath could apparently be considered a sign of the development of detraining of the cardio-respiratory system as a result of limiting man's muscular activity. /22

In practically all experiments conducted, the average group maximum values of heart contraction frequency obtained during veloergometric tests before and after bed rest, were very close and gave evidence of high stress of the cardiovascular system while performing the work. In these cases, the maximum oxygen consumption and volume of work performed serve as an excellent indicator of the restructuring of a given system's functional reserve.

ACTIVITY OF THE HUMAN HEART DURING SPACE FLIGHT AND WHEN SIMULATED IN EARTH EXPERIMENTS. /23

Examinations of cosmonauts during and after orbital flight of varying duration have shown that one manifestation of the unfavorable effect of weightlessness on man's cardiovascular system may be the development of impaired heart activity.

An analysis of our observations and data published by our American colleagues permits us to outline the following most commonly observed changes in cosmonaut's heart activity:

- increased lability of pulse and inadequate change of frequency of heart contractions during emotional, physical, and gravitational loads;

- a variety of impairments of heart contraction rhythm in a state of rest and under physical stress: bradycardia, ventricular tachycardia, singular or multiple atrioventricular, atrial or polytope extrasystoles and so forth;

- impairment of atrioventricular or intraventricular conductivity;
- change of bioelectrical activity of the myocardium, heart tones and phase structure of heart contraction;
- change of configuration and decrease of the dimensions of the heart's X-ray shadow.

During and after flight some cosmonauts complained that even during moderate physical stress there appeared unpleasant sensations or pains in the heart regions. The above-indicated changes were more clearly expressed while conducting load tests (work on the veloergometer, the effect of ODNT, and the like), particularly when examined directly /24 after completing space flights. It should be emphasized that changes noted in heart activity of cosmonauts thus far have, as a rule, been of a functional nature and have not posed serious dangers to their health. However, the prognostic and scientific significance of deviations in heart activity that have been revealed is, in our view, quite great, particularly since they have been very clearly expressed in individual cases and have indicated somewhat of a reduction in the contractive functioning of the myocardium and of the functional reserve of cosmonauts' hearts.

In any case, there has thus far been accumulated a sufficiently great amount of data attesting to this possibility, at least in principle, of impairment of man's heart activity under conditions of space flight, as well as the necessity of conducting research directed toward the study of the mechanisms for the development of such impairments and the search for the most practical methods of preventing and cutting them short. In this regard, impairment of the functioning of conductivity and heart contraction rhythm, periodically observed in Soviet and American cosmonauts, warrants particular attention. The etiology of these heart contractions remains unclear at the present time.

Earth experiments in simulating individual factors of space flight and, above all, weightlessness and hypokinesis, can offer substantial help in solving such problems. In this regard, there is great practical significance in the fact that, as shown by numerous experiments

in simulating weightlessness using bed rest and immersion, it is possible to reproduce, under Earth conditions, many impairments of human /25 heart activity that are observed during and after space flight.

We have thus far conducted a great number of experiments using antiorthostatic hypokinesis in which heart activity has been studied. Changes have been revealed that are very similar in direction to those that take place during and after space flight.

These are chiefly various types of impairments of the rhythm of heart contractions (sinus arrhythmia, bradycardia and extrasystolia), change in the myocardium's bioelectrical activity in a state of rest and the appearance of signs of relative or absolute deficiency when performing load tests.

In several subjects examined directly after the experiments, the signs of lowering the functional reserves of the heart during the load tests were very clearly manifested. This was an impairment of the bioelectrical activity of the heart attesting the hypoxia of the myocardium and a strong impairment of the rhythm of the heart contractions (slide 3, 4) culminating in a sudden stopping of the heart for 12 seconds in one of the subjects during a test with ODNТ on the 25th day of antiorthostatic hypokinesis. A comparative analysis of the data on the influence of hypokinesis at various angles of tilt on the heart's bioelectrical activity has shown that the somewhat more pronounced impairment of the myocardium's functioning takes place only in experiments of relatively small duration (on the order of 1-2 weeks), i.e., during the "active adaptation" period. In more prolonged experiments, (30 days or more), the direction of changes and the degree of their expression was practically identical. This is apparently linked with the dominant influence of hypokinesis as such, and with the fact that even during hypokinesis in a horizontal position there is a certain redistribution of blood in the vessels of the upper half of the body. The difference in the degree of redistribution of blood brought about by the angle of body tilt of subjects against the background of the entire process of detraining of the cardiovascular system probably does not play such a substantial role in the development of the observed changes of the myocardium's bioelectrical activity.

As an example, we might offer data obtained during a 30-day experiment, during which 18 persons were under constant hypokinesis in various body positions. The subjects were divided into four groups of six persons each. The angle of tilt of the subjects in groups 2 and 3 was equal to -2° and -6° , respectively (antiorthostatic hypokinesis) and those of the first group were at $+6^{\circ}$ (orthostatic hypokinesis). A fourth group of subjects (6 persons) served as the control. These persons were in a normal, customary routine of movements.

The illustration shows the amplitude of peaks T, registered in these subjects in a state of rest before (white columns) and after (dark columns) 30 days spent under the described experimental conditions. From this illustration, it can be seen that in subjects who were in hypokinesis at various tilt angles, the degree and direction of changes in the peaks T were approximately identical. In subjects of the control group, changes in the amplitude of the peaks T over the same period of time were practically absent, permitting us to associate the observed shifts with the effect of the experimental factor under study. /27

Naturally, the neutralized data presented in the illustration reflects only the general direction of the change of amplitude of peaks T during the experiment, inasmuch as the degree and localization of the changes is characterized by a certain individual dispersion: from a moderate reduction of the amplitude of the T peaks in all abductions to a considerable one - primarily in abductions characterizing the condition of the myocardium of the left ventricle. In several subjects, a considerable lowering of T peaks was accompanied by their deformation and the formation of the T_{Y1} T_{Y6} syndrome, basically due to depression of the T peaks in the left precordial abductions.

As regards the other parameters characterizing man's heart activity under conditions of hypokinesis (for example, indicators of the myocardium's contractive functioning, heart chamber, volume, etc.), the change, in a number of cases, depended on the angle of tilt of the body of the subjects during the experimental period. However, in view of the relatively small number of observations, the final establishment of this regularity requires further research.

It should be noted that, as during hypokinesis in a horizontal position, the impairment of the heart activity of the subjects in the experimental groups after completing bed rest was more clearly expressed while conducting load tests. While conducting orthostatic tests and the ODNT (-40 mm mercury column for 10 minutes) at the height of loads, there appeared EKG changes, characteristic of relative or absolute hypoxia of the myocardium - predominantly of the left ventricle of the heart. In a number of subjects, there were unpleasant or painful sensations in the heart regions, and a pronounced impairment of the rhythm of heart contractions, as well as conduction function.

It is characteristic that the development of the above-indicated impairments of the subjects' heart activity took place against the /28 background of a lowering of the cardiovascular system's functional potentials as a whole. During an examination at the end of the experimental period, all subjects were less able to undergo both functional loads; difficult subjective passages of test, more pronounced change of frequency of heart contractions and arterial blood pressure, more pronounced reduction of systolic output and so forth.

In contrast to the background period, in nine subjects of the experimental groups there was noted after hypokinesis an extreme lowering of resistance to the functional tests - the development of a pre-collapse or collapse state. In six of them, this occurred during both tests.

It should be emphasized that when conducting Earth models of experiments in a number of cases the degree of impairment of the activity of the heart was more clearly expressed than during and after orbital flights, going as far as focal hypoxia of the myocardium and brief asystolia of the heart while conducting the load tests. In individual cases, the appearance of changes in the bioelectrical activity of the myocardium (lowering of the amplitude and change in the form of the extreme part of the EKG ventricular complex) was accompanied by the appearance of pains in the heart region and other clinical signs of impairment of heart functioning.

The relatively great degree of impairment of heart functioning

in Earth experiments is, in our view, associated with the more "strict" /29 selection of cosmonaut candidates and with the fact that various preventive measures are constantly used during space flights, including making up for the lack of movement. However, this may be caused also by the incomparable smaller number of observations under conditions of actual space flight, particularly prolonged flights. The latter "raises" the probability of developing similar (more serious) impairments during and after orbital flights. This is all the more true, since the complexity of the scientific programs of space flights has made it vital to have high-class specialists on board orbital stations. The average age of these specialists in recent years has been 40 years and more, and this in itself has considerably increased the risk of cardiovascular impairment.

Thus, up to the present time a certain amount of data has been accumulated that attests to the urgency of the problem of finding means of prevention and treatment of impairments in the heart activity of humans during and after a space flight. Naturally, the solution of this problem is impossible without the development of observed impairments. At the base of these impairments apparently lie such factors as general lack of conditioning of the cardiovascular system, hemodynamic shifts, chronic stress and restructuring of the interchange processes of cosmonauts' organisms.

Which of these factors is dominant in the development of observed deviations in cosmonaut's heart activity has not yet been fully established. To a considerable degree, this is linked with the relatively small number of observations (particularly in prolonged flights) and the limited technical potentials for cardiological examination on board orbital stations, for instance, due to the strict weight requirements for on-board scientific medical research equipment and the absence of a medically-trained researcher. /30

The development of optimal treatment and preventive measures is to a considerable degree impeded; because to this day there remains doubt as to what degree the observed changes in heart functioning are caused by impairment of coronary blood circulation, and to what degree by a change in the myocardium's metabolism.

In light of what has been said, the necessity of intensifying scientific and research work on the influence of space flight factors on human heart activity becomes apparent. We feel that a number of questions can be answered only while conducting Earth experiments, where there is the opportunity to study the intricate mechanisms of heart activity impairment under weightlessness simulation, using modern methods of cardiological examination that are incomparably more informative than "on-board" ones.

Thus, the experiments conducted have shown that, for reproducing the circulatory disorders that arise in a weightless state, as well as after completion of a space flight during re-adaptation to Earth's gravity, antiorthostatic hypokinesia is a more adequate experimental model than bed rest in a horizontal body position.

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